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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,449,477,** on November 14, 2003, by **HYDRO-QUÉBEC,** assignee of Eric Lavoie, Lionel Reynaud, Gilles Rousseau, Jacques Bherer and François Léonard, for "Development of the Métar Family of Feeder Inspection Tools".

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DEVELOPMENT OF THE *MÉTAR* FAMILY OF FEEDER INSPECTION TOOLS

The present invention relates to development of inspection devices for the feeder tubes of CANDU power plants. The first tool is the Métar bracelet, consisting of 14 ultrasonic probes held in place in a rigid bracelet to measure the thickness of the pipes and moved around manually along the pipe. A motorized version, i.e. the *Crawler*, is able to inspect beyond the operator arm's reach to access hard-to-reach places or further down the pipes in the reactor. A motorized 2-axis crack detection device is also provided to answer new concerns about the feeder. Other configurations, depending on the demands from the industry, can also be developed for specific inspection needs, for example; inspection of the graylock welds, 360° inspection of feeders, or multitasking of inspection on a single frame, etc.

An object of the invention is to improve and develop new tools to further expand feeder inspection. Always addressing new inspection needs or request, the family of Métar inspection device is composed of 4 different lines of product: The *Manual Métar*, for thickness inspection of the first and second bends when they are accessible at arms reach, the motorized Métar, ie the *Crawler*, designed to reach longer distance where the Métar cannot go, the *Cracking Scanner*, a mechanized device to detect axial cracks and flaws next to the first elbow grayloc, and the *Orbital Scanner*, a multi-purpose scanner able to scan all around the feeders with different probes. All these devices satisfy the G2 needs and specifications but can be, if not already, adapted to most of the CANDU site with minimal development.

Manual Métar

The manual Métar is the first feeder inspection device to provide fast and efficient in-situ feeder thickness measurement. The device consists of a frame that clips on the feeder and a probe holding collar, consisting of 14 UT sensors, inserted in the frame. Different sizes of frames can be provided to adapt to different feeder diameters. The frames are equipped with an encoder. The collar remains the same for all size feeders. Once the bracelet, with the collar, is installed on the feeder, the operator just has to push it along the feeder to scan the whole extrados in one pass. Depending on the feeder size, 140 to 170 degrees of circumference of the feeders is covered in each pass, which is enough to encompass the critical area of the extrados. The Métar may also cover the intrados provided that it is positioned correctly from the beginning. In fact, critical feeders may completely be scanned in 4 passes in order to generate complete thickness maps for fitness-for-service analysis.

Data gathered by the UT probes and the encoder are sent to the acquisition system, which stores them for analysis. US patent no 6,497,159 (Lavoie) teaches both the frame and the collar as novel pipe inspection device.

Metarview

The data analysis technique developed for METAR is time-consuming and the accuracy can be improved by digital signal processing. The standard analysis

procedure provides a measurement accuracy of +-0,030 mm [2]. Complete mapping of a feeder for fitness-for-service analysis takes typically 2 1/2 days of work. Considering the importance of establishing thinning rate and to complete studies needed for ageing management, a faster and more accurate analysis method is desirable.

Higher accuracy can be achieved by applying interpolation techniques but this requires to unload all the computational work to a computer. A complete analysis package, Metarview, can be provided, which converts ultrasonic time-of-flight measurement into a thickness map. The computer display is similar to the data-acquisition display, i.e. it provides a thickness C-scan map with axial and circumferential cross-sections (B and D-scans) and the raw ultrasonic data (A-scan) - although it adds a 3D thickness graphical view. The main difference resides in the tools available to the analyst. The analyst has the choice between several calculation techniques: zero-crossing interpolation, cross-correlation interpolation and other advanced cross-correlation interpolation. The analyst has full control over the area to process; he can either work on the entire scan or focus his attention on a region of interest. The software provides automatic localization of the minimum and the analyst can review and accept or reject any data point with one mouse click. Thickness can also be averaged over a user-defined area and metal loss may be calculated by comparing data from previous years. The thickness map values can be exported into a spreadsheet file for backup and manual analysis, as well as any A-scan information (file name, coordinates, thickness, file minimum thickness, etc...).

All adjustments of the interpolation parameters are fully programmable in dedicated windows and the analyst can experiment in real-time with the current file the effect of a setting. Once he is satisfied with the settings, they are saved and the analysis resumes with the latest changes. Any new opened file will use the latest settings as default settings. At the time of writing this paper, only one reference waveform is built for all transducers. The next version will allow to build a reference waveform for each transducer thus improving thickness measurement accuracy.

The Crawler

The Motorized Métar, ie the *Crawler*, is the next step in the Métar development program. The main goal of the motorized version is to relieve the operator from pushing the bracelet along the pipe, thus resulting in a lower exposure to radiation. New applications with the motorized Métar are also possible, e.g. to send UT inspection probes in places otherwise inaccessible, e.g. locations such as the upper feeder cabinet. For G2 purpose, the crawler is designed to be able to scan from the graylock all the way passed the straight section following the second bends, especially for the longer radius bends (type 6 to 10 on a CANDU 6) and to be able to pass under the locking mechanism, which causes a major space restriction in this area. Basically, the crawler is similar to the Métar, except that wheels are now motorized and a miniature camera and light is added for remote visual inspection. It uses the same probe collar and sensors, making retrieved collected data and analysis tools compatible between the technologies.

As mentioned above, the Crawler is similar in shape and design to the manual Métar. It consists of a frame, different for each feeder size, and a collar holding 14 UT

probes (or more or less). A driving mechanism permitting to motorize the roller is provided to propel the bracelet. The drive mechanism consists of a motor, connected to the frame via a flexible shaft in a semi rigid casing, a set of worm gears between the shaft and the rollers, also linked with another small flexible shaft, which transfers the power to the rollers. The motor can be located about 3 feet away from the frame, in the cabling bundle, to use less space and cause less restriction in an already very restricted location. The motor may also be located in a control box about 20 feet away from the bracelet and linked with an extra long flexible shaft, if desired. But this configuration is likely to be less convenient when the system is deployed in more confined spaces. A drive camera and lights are provided to let the operator sees where the bracelet is going. The closure mechanism on the Crawler frame is adapted to facilitate the installation and removal of the bracelet. A tensioning system permits to adjust the tension on the drive wheels to assure optimum traction in every situation. This tensioning system, which can be operated from a distance with a cable, like a bicycle brake, is especially useful to retrieve the Crawler in case of a mechanical failure while out of hand reach. As for the manual Métar, the collar in the Crawler needs to be supplied with couplant in order to maintain good contact between the probe holders and the surfaces. The crawler equipment consists of the frames, the collar, the drive mechanism, including the couplant feed manifold, the couplant pump and tubing, the drive controller, the closing mechanism pliers and wire and all the cabling for the motor, camera, light, etc..

Tests of the crawler have been successfully performed on a reactor by doing a couple of up an down runs on an easily accessible feeder. The scope of inspection covered some long runs inspection at the face of the reactor, and sometimes very crowded area, and some very hard to reach bends over the freezing cans, in a very high radiation area (1000 to 1500 mR/hr). 4 different sizes of frame were built, 2.0", 2.5", 3.0" and 3.5", the last 2 being for the upper feeders in the isolation cabinet. Other tests of the crawler have been performed for G2 needs. This time, the inspection took place in the isolation cabinet, to inspect feeder sections between the outlet header and spring loaded supports. The crawler was installed on the bend welded to the header next to the DN lines and ran under the header for a fixed distance, close to the collector in very hard to reach area. Following this inspection, a floating motor system, where the drive motor is in line in the cabling bundle, was conceived. The closure system can be adapted for one-hand operation.

Crack Detection

Following an incident involving feeder cracking at a PLGS plant, it has been decided to develop a device to facilitate crack detection in a feeder tube. The resulting device, fully motorized, once again permits better crack detection while lowering doses and permitting to store the inspection data for better analysis of collected data. The purpose of the new scanner is to mechanically imitate every aspect of the procedure develop by the COG NDT team, often referred to as the V18 procedure, but with four probes at once, reducing inspection time and thus radiation exposure. The cracking scanner is designed to inspect the first bend of the 2.5 inches feeder (type 6), more specifically the lower ones attached to a cantilever support, where 4 out of 5 cracks appeared at PLGS. Other sizes of scanner may be conceived. Probes used for crack detection may be ¼ inch UT probes mounted on a 45 degree probe holder. No

liquid couplant feed is necessary since it can easily by put on by the operator with a brush prior to the scanner installation.

The Cracking Scanner is based on a similar principle as the Métar bracelet. It has a rigid frame with traction rollers with UT sensors in the middle. There are 4 sensor transducers mounted on 45-degree angle wedge aligned on the feeder. Wedges, which are contoured to better fit the feeder shape, are linked together and can move circumferentially about ½ inch. This movement is necessary for the ultrasound beam to cover the whole volume to be inspected. By design, the scanner can inspect both cheeks of the feeder at the same time, and depending on the UT instrument settings, can go all the way around of the feeder. Only a middle portion on the extrados is possibly not covered by the inspection, but study shows that it is very unlikely the cracks could appear there. The holders are couple in pairs, 2 on each side, and they are linked together to create the scanning motion. Spring loading assures the wedges to stay in contact with the surface. The closing mechanism is manual and very straightforward, requesting very few manipulations from the operator. Traction is achieved using magnetized rollers, which also help keeping the scanner in position in the presence of very slippery couplant (Hamikleer™). Since the distance to cover is minimal (150 mm), and that traction is rather good because of the magnets, no outside encoder has been fitted on this bracelet. To calculate displacement, the encoder integrated in the motors is used, making for less wear parts.

The development of the motorized crack detection scanner included determining that it was possible to recreate standard inspection procedure (in this case V18) with a fully motorized device, doing 4 scans in one pass, leaving very few inputs from the operator. The Cracking Scanner is able to inspect more than 40 feeders at a working rhythm of less than 10 minutes per feeders, including pipe preparation, installation, inspection, removal and couplant wiping at the end.

Orbital Scanner (Multipurpose Scanner)

There is a need for a device able to inspect all the way around the feeders. A multipurpose scanner able to scan 360 degree of feeder with different probes (UT, ET or phased array) is provided for this purpose. Thickness measurement at the graylock welds, an area that the Métar cannot covers, was first considered. But the happening of a possible leak in a feeder at G2 reoriented the development towards a scanner capable to perform an entire weld inspection with normal and angle beam search units, meeting the requirements of CSA/ASME codes. This scanner, dubbed the *Orbital Scanner*, possess 2 probes at 180 degree that can rotate 180 degree around the feeder, covering all the way around circumference of the pipe. The probes wedges are mounted in a spring loaded support, ensuring good contact between the holders and the feeder and adjusting to variations in shape of the surface to inspect. For this particular inspection, normal and angled beam probe holders were used, but other NDE techniques could also be achieved, as long as the probes can be adapted to the scanner.

The scanner can be adapted to locate a flaw prior to the feeder removal and to perform mechanized ultrasonic inpection of the spool piece welds. The Orbital Scanner may have both motors on the same side of the frame, making it a lot easier to manipulate. Also, proper design of the latching mechanism may facilitate installation

and removal of the bracelet, especially with one hand or in very hard to reach position.

CANDU 6's are affected by unexpected feeder thinning near the grayloc hub. This problem, identified at PLGS in 1996, was also confirmed to affect G-2. METAR was proven to be the right tool to achieve 100% inspection of all feeders. The quality of the data and its accuracy help identifying feeders mostly affected by thinning, to experiment a mitigation technique with the most critical feeders (use of depleted fuel to cut boiling, for instance), and to make accurate prediction as for the remaining life of every feeder.

METAR can be used at G-2 and PLGS to measure thinning rate on the elbow next to the outlet headers. Because of the restricted access caused by DN lines welded to the feeders approximately 1 meter below the header, the Crawler should be used to extend the thickness inspection beyond the DN line connection toward the F/C connection. Decision about refurbishing the upper feeder cabinet can be based mainly on these inspections.

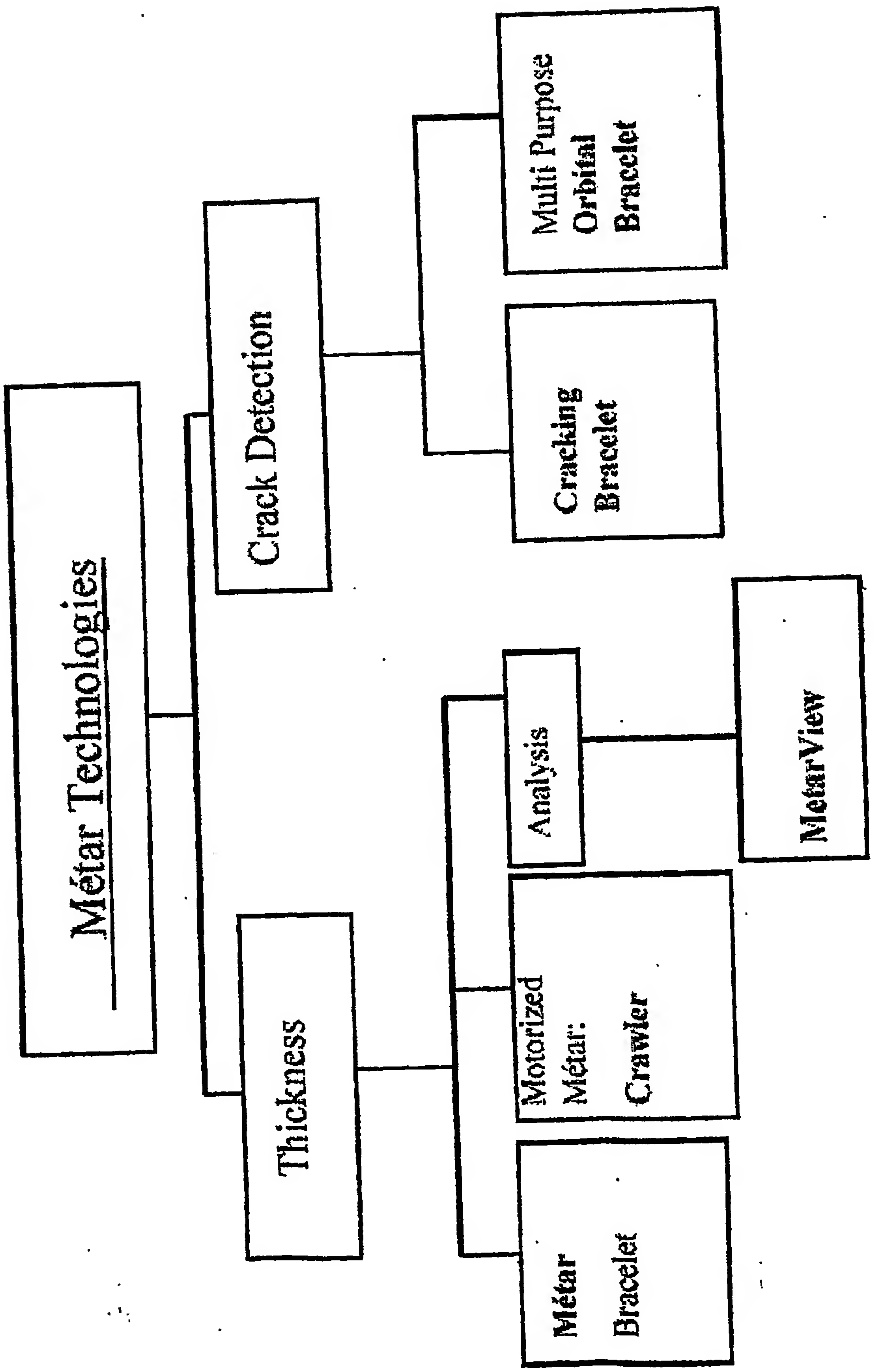
The motorized cracking inspection device is particularly useful at recording the inspection data. The inspection method can be improved because the transducers can be moved closer to the area of concern and the position of each transducer is precisely recorded with the ultrasonic waveform thus providing the ability to analyse with computer-imaging techniques. Motorizing the inspection reduces radiation dose by combining the detection and verification scans and by performing the four detection scans in one pass, thus reducing the inspection time from 5 to 2 minutes. Inspection rates of 10 feeders per hours can be achieved when the bridge does not need to be repositioned. With the previous manual inspection method, the inspection speed was typically 25 feeders per shift. This rate can be doubled with the used of the motorized scanner.

References

1. Eric Lavoie, Gilles Rousseau, Jean Lessard, Alain Drolet "Hydro-Québec METAR Inspection Bracelet", CNS 5th International Conference on CANDU Maintenance, November 2000.

2. Gilles Rousseau "Qualification du bracelet METAR et du système d'acquisition □Tomoscan pour l'inspection des tubes d'alimentation du réacteur", Rapport R#D Tech D/4297-03, June 2000.

3. Edward Ginzel, «Report on the mechanization of a Crack Detection Method using a Modified Guided Wave Technique», Materials Research Institute, Waterloo, Ontario, August 22, 2003.


Métar Technologies
Crack Detection
Thickness
Multi Purpose Orbital Bracelet
Cracking Bracelet
Analysis
MetarView
Motorized Métar: Crawler
Métar Bracelet

Feeder Inspection at G2

- 344 feeders inspected at G2 (502 bends)
  - Identification of the most affected feeders.
  - Experimentation with a mitigation technique for the most critical (depleted fuel to cut boiling for instance).
  - Accurate prediction as for the remaining life of the feeders.
- Thinning rate next to outlet feeders at G2 and PLGS (Métar and Crawler)
  - ~100 locations visited.
  - No other data concerning these area exist.
  - Essential to plan refurbishment.
- Motorized cracking inspection
  - Aimed at recording the data and the position of the transducers.
  - Improvement of V18 procedure.
  - Diminution of radiation exposure.
  - Double the inspection rate.
- G09 leak and accelerated development;
  - Leak on the field weld in a high radiation area.
  - Mechanized weld inspection to minimize dose.
  - Very short development time (< 2 months)
  - Ultrasonic procedure to be developed and validated before repair for both manual and mechanized inspection.
  - Validation of welding techniques and operator.

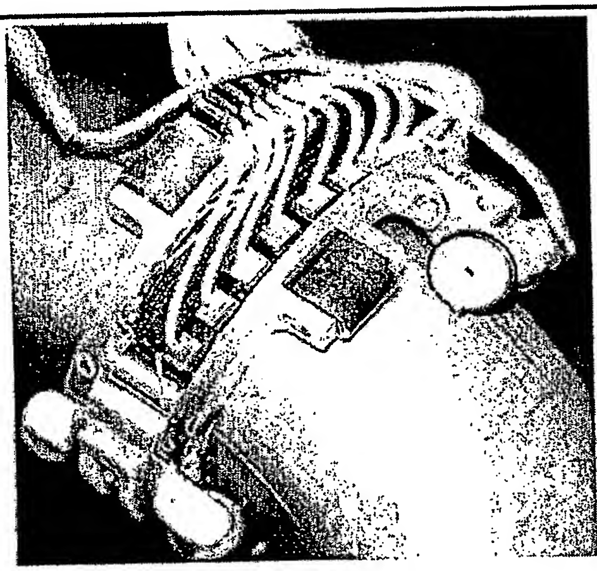


Figure 1 Métar Bracelet

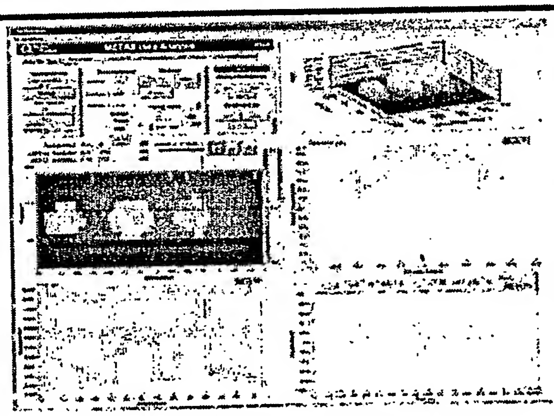


Figure 2 Metarview front panel

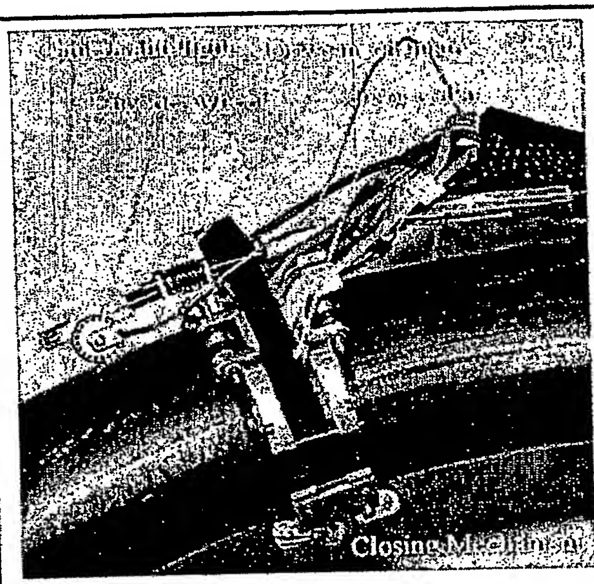


Figure 3 Motorized Métar, the Crawler

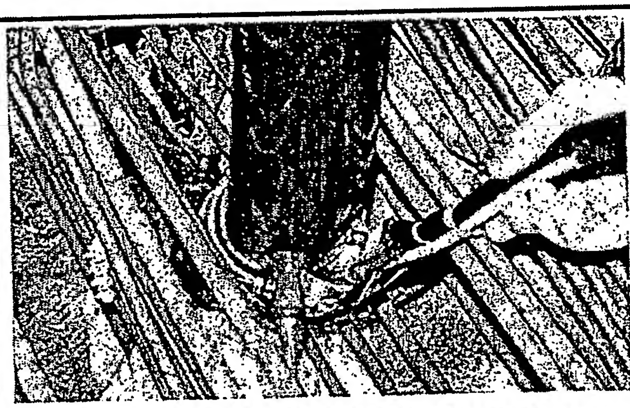
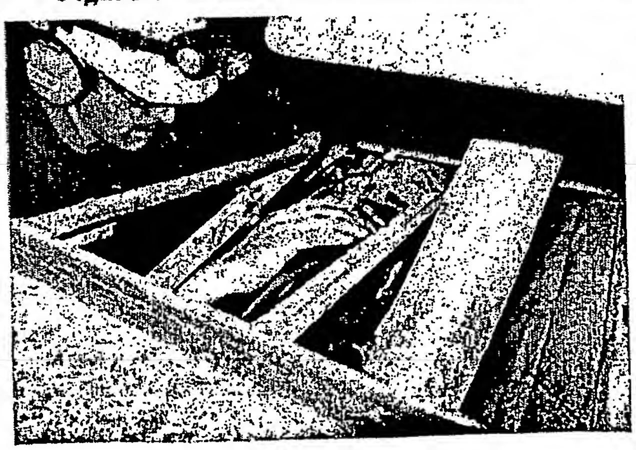


Figure 4 2002 PLGS Crawler Inspection



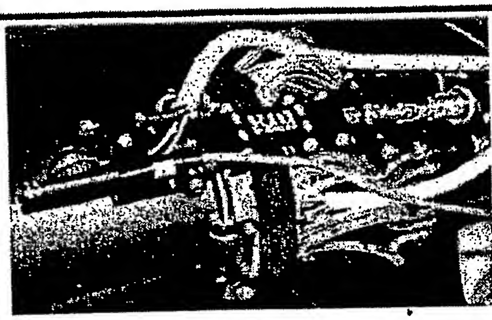


Figure 5; Rd Tech Crawler

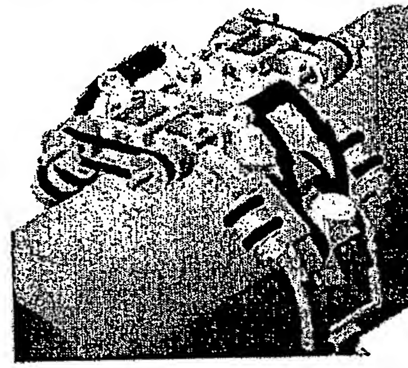


Figure 6 Cracking Scanner (motors removed)

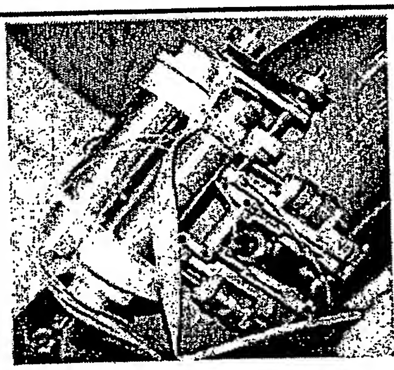


Figure 7 Crack detection Scanner (June 2003)

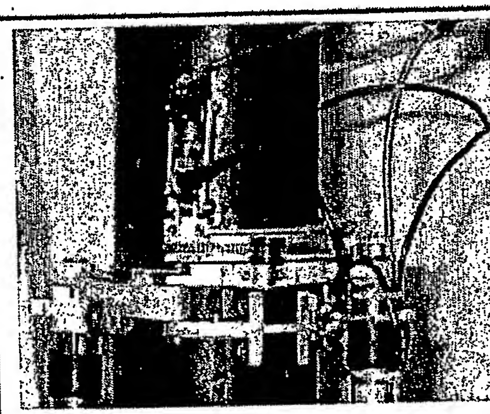


Figure 8 1st Prototype, Orbital Scanner

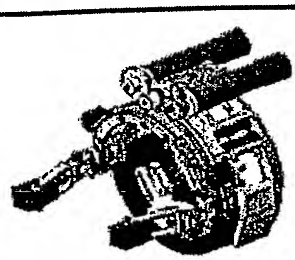
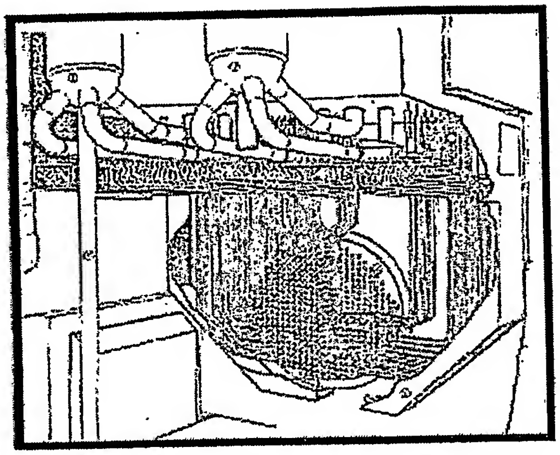
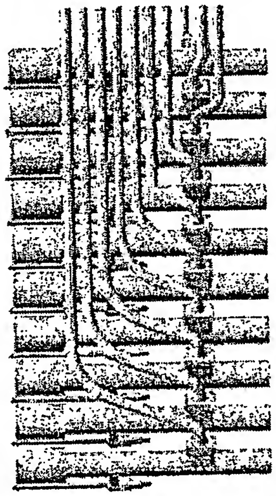
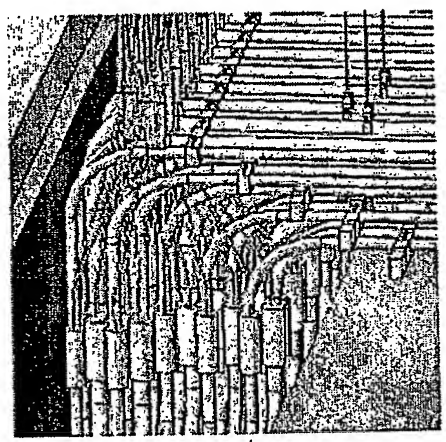
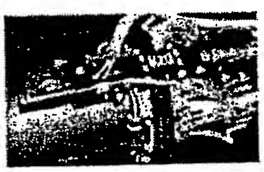


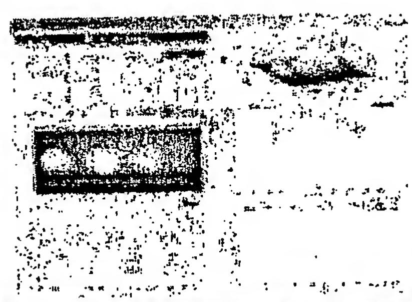
Figure 9 Orbital Scanner

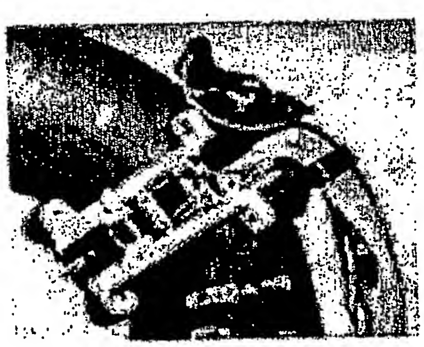




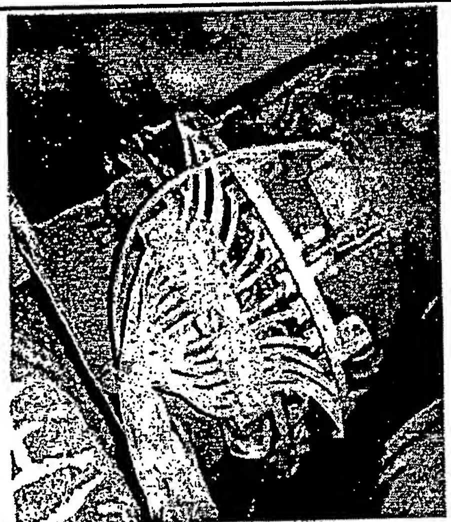






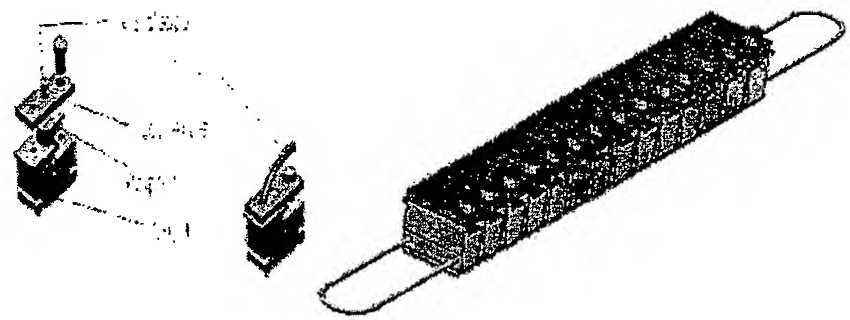


Métar Bracelet

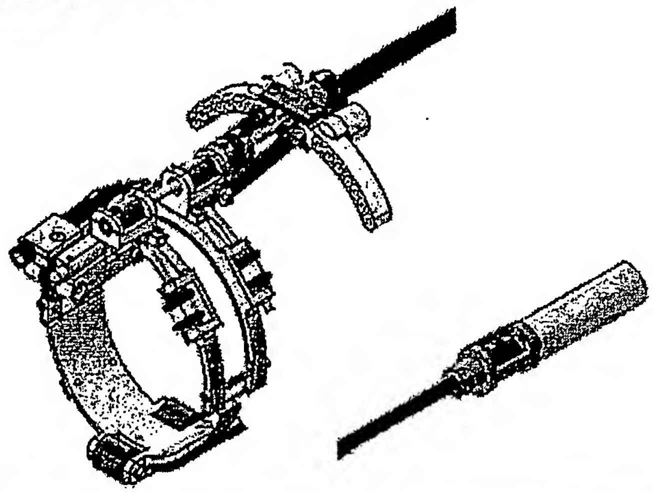


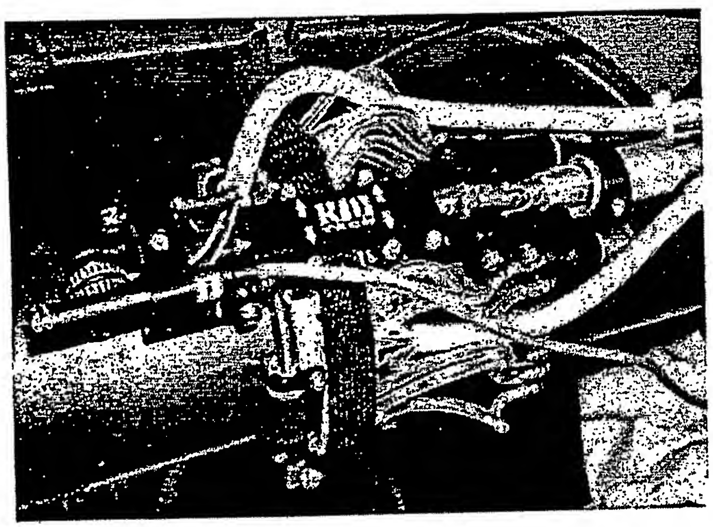
- Scope
  - Thickness measurement for the first and second elbows.
- Characteristics
  - 14 UT sensors mounted in a flexible collar attached to a rigid frame
  - Many different sizes available
  - Easy to install and handle

- Used in the majority of CANDU plants



Motorized Métar: the Crawler



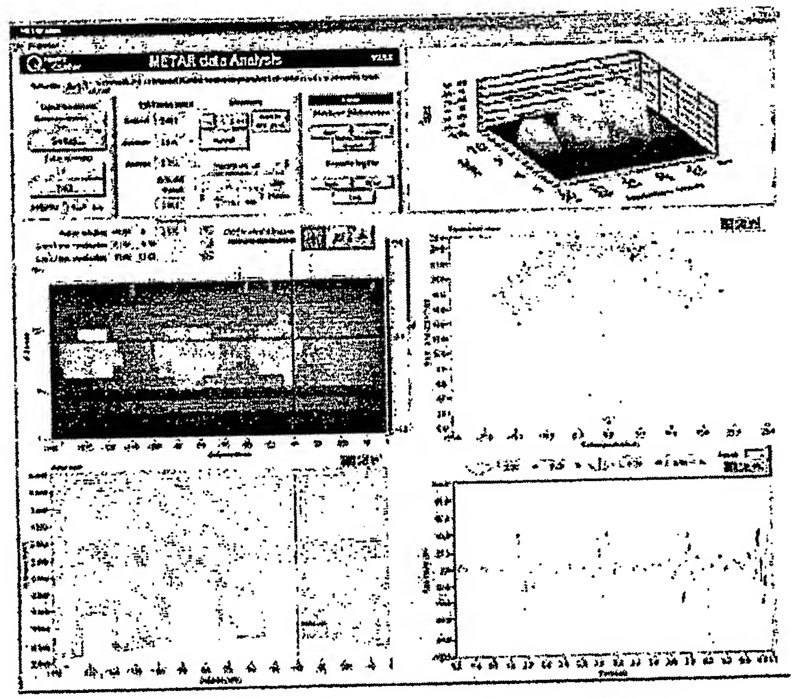


- Scope
  - Thickness mapping for inaccessible position
- Characteristics
  - 14 UT sensors in flexible collar
  - Floating motor system
  - Remotely controlled closing system for emergency retrieval
  - On board camera and light

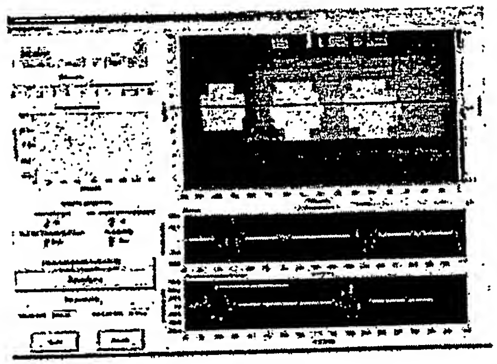
Métarview

- Scope
  - Analysis software for Métar thickness data.

- Characteristics:
  - Diminution of analysis time
  - Real thickness representation
  - Reads Tomoview files (.rdt) directly
  - Tomoview-like visualisation
  - Active 3-D representation
  - Optimum points search
  - Analysis logbook
  - Parameter optimisation



Métarview



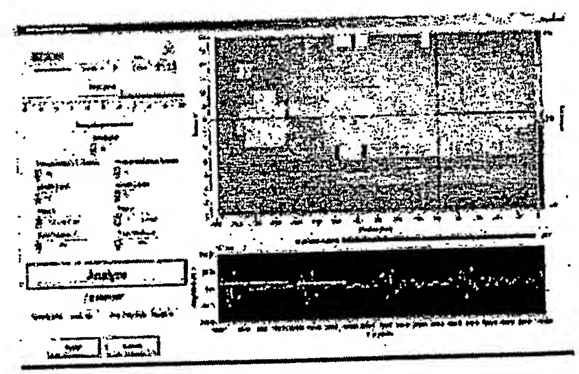
Set-up window for cross corelation

Cross correlation

- based on the interpretation of the distance between the maximum correlation peaks of the first two echoes
  - Works well even if A-scan signal is noisy or contains superposed reflexions
  - Easy to adjust parameters
  - Less accurate if signals are saturated
  - Many techniques developed
    - Fast cross correlation
    - Advanced cross correlation
    - And more ...

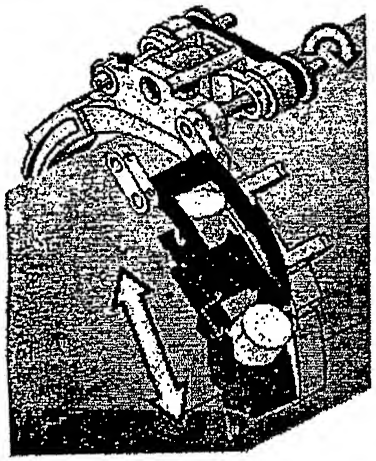
Zero crossing

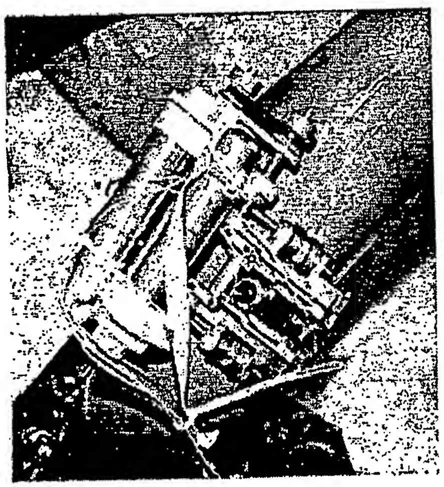
- based on the interpretation of the distance between the zero-crossing locations of the first two successive echoes
  - Fastest than cross correlation
  - Works well if A-scan signal is clear (low noise & no superposed reflexions)
  - Works if A-scan signal is saturated
  - Longer to adjust parameters than cross correlation



Set-up window for zero crossing

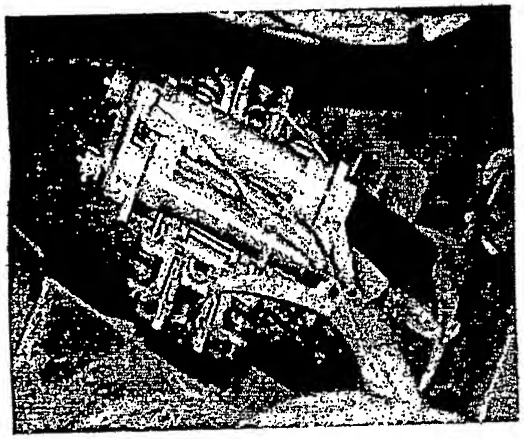
Cracking Bracelet

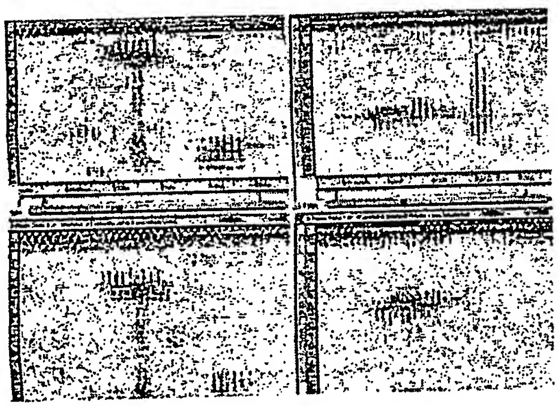


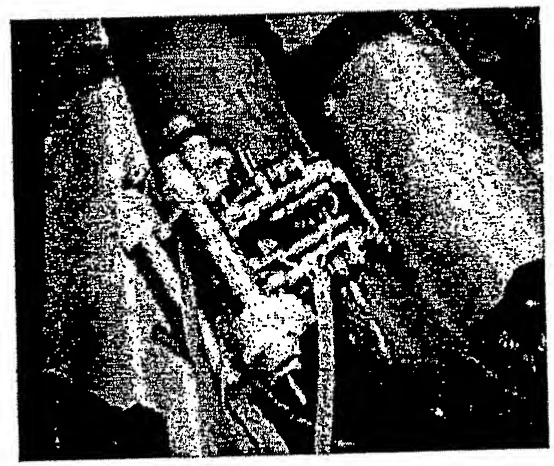


- Scope:
  - Detect cracks on the cheeks of the first elbow of the feeders.
  - 4 UT probes on angular wedge (45 degree)
  - According to V18 inspection procedure.
  - Single pass to scan elbow.
  - 18 mm alternative motion to cover all the surface.
- Characteristics
  - Compact and easy to install
  - Magnetic wheel for ease of installation and better grip
  - Ameclear couplant applied manually before scan
  - No intervention once installed
  - Data collection for future reference in Tomoview

Cracking bracelet

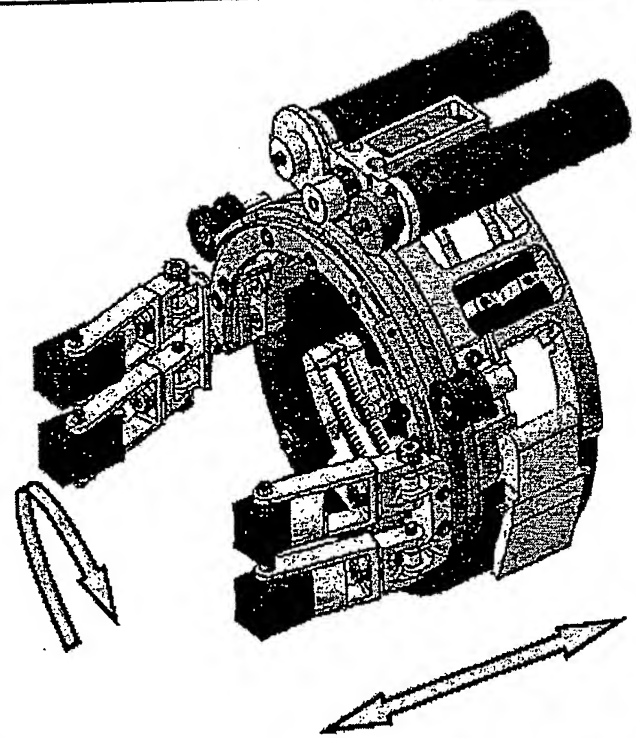




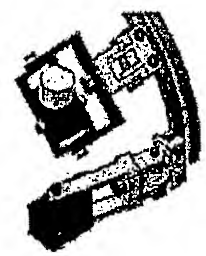


Orbital Scanner

- Scope:
  - Multipurpose scanner for 360 degree scan
  - Crack detection (axially or circumferentially)
  - Field weld inspection
  - Thickness mapping
  - 4 UT probes in different wedges, depending on needs and inspection
- Characteristics
  - Simple one handed closing mechanism for end of reach installation.
  - Magnetic wheels
  - 2 sizes available: 2.0 et 2.5 inches
  - Couplant fed directly through wedge
  - Multi Purpose and easily adaptable



Angular scan for axial cracks



Forward and circular scans

Thickness Scan

Orbital Scanner